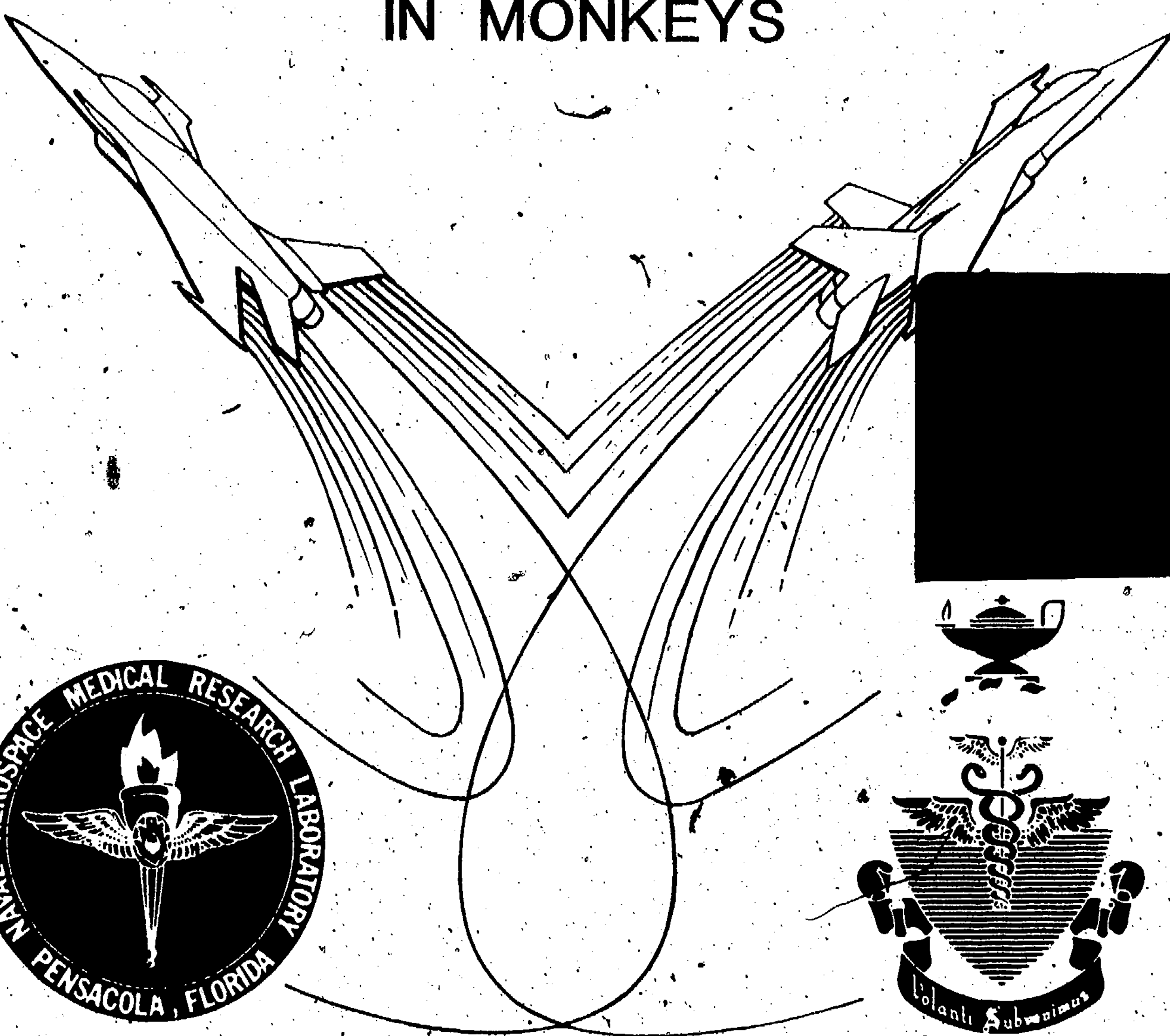
AD-A283 667

NAMRL-1358

USAFSAM-TR-90-14

NO EFFECTS OF HIGH-PEAK-POWER MICROWAVE PULSES AT 2.36 GHz ON BEHAVIORAL PERFORMANCE IN MONKEYS



[redacted]

NAVAL AEROSPACE MEDICAL RESEARCH LABORATORY PENSACOLA, FLORIDA

Volanti Subvenimus

JUNE 1990

NOTICES

This interim report was submitted jointly by personnel of the Naval Aerospace Medical Research Laboratory, Pensacola, Florida, and the Radiation Sciences Division, USAF School of Aerospace Medicine, Human Systems Division, AFSC, Brooks Air Force Base, Texas.

This research was sponsored by the Naval Medical Research and Development Command under work unit 62758N MM58524.002-0010 and in part by the U.S. Air Force School of Aerospace Medicine under job order 7757-01-1M.

The animals used in this work were handled in accordance with the principles outlined in the Guide for the Care and Use of Laboratory Animals, prepared by the Committee on Care and Use of Laboratory Animals of the Institute of Laboratory Animals Resources, National Research Council, DHHS, NIH Publication No. 85-23, 1985; and the Animal Welfare Act of 1986, as amended.

This report has been reviewed and is approved for publication.

John A. D'Andrea

JOHN A. D'ANDREA, Ph.D.
Project Scientist

B. Jon Klauenberg

B. JOHN KLAUENBERG, Ph.D.
Project Scientist

John O. DeLorge

JOHN O. DELORGE, Ph.D.
Head, Aviation Performance Division

John C Mitchell

JOHN C. MITCHELL
Chief, Radiation Sciences
Senior Executive

James A. Brady

JAMES A. BRADY, CAPT, MSC, USN
Commanding Officer

George Schwender MD

GEORGE E. SCHWENDER, Col, USAF, MC, CFS
Commander, USAFSAM

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 1990

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
No Effects of High-Peak-Power Microwave Pulses at 2.36 GHz on Behavioral Performance in Monkeys

5. FUNDING NUMBERS
62758N
MM58524.002 0010

6. AUTHOR(S)
J.A. D'Andrea, B.L. Cobb, J. Knepton, R.N. Shull, B.J. Klauenberg, J.H. Merritt, and D.N. Erwin

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Aerospace Medical Research Laboratory
Bldg. 1954, Naval Air Station
Pensacola, FL 32508-5700

8. PERFORMING ORGANIZATION REPORT NUMBER
NAMRL-1358
USAFSAM-TR-90-14

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Medical Research and Development Command
National Naval Medical Center, Bldg. 1
Bethesda, MD 20814-5044

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Recent development of new microwave systems with very high-peak-power microwave pulses and other unique characteristics has increased concern for the safety of personnel working in and around such equipment. The objective of this experiment was to determine the effects of high-peak-power microwaves produced by a virtual cathode oscillator (VIRCATOR) on the performance of rhesus monkeys (Macaca mulatta). The monkeys were repeatedly exposed to high-peak-power, short-duration microwave pulses (50-80 ns) delivered concurrently with auditory signals to which the monkeys were trained to respond. In addition, sham exposures were conducted by shielding the monkeys from the microwave pulses using an aluminum foil barrier. Compared to sham-exposure sessions, the microwave pulses did not produce statistically significant effects on behavioral performance. This experiment demonstrated that exposure to short high-peak-power microwave pulses with very large peak SARs (365-827 kW/kg) but low whole-body average SARs (less than 0.1 W/kg) did not significantly alter a well-trained behavior. Therefore, the whole-body SAR limit of 0.4 W/kg and the part-body SAR limit of 8 W/kg for human exposure to microwave energy remains justified.

14. SUBJECT TERMS
Microwave, High Peak Power, Behavior

15. NUMBER OF PAGES
17

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

SUMMARY

Military personnel may be frequently exposed to low-level microwave radiation from guidance, communications, and weapons systems operating at various frequencies and power densities. Recent development of new systems with very high-peak-power microwave pulses and other unique characteristics has increased concern for the safety of personnel working in and around such microwave environments. Additional information is needed to define microwave levels, identify hazards, and specify safe exposure standards of operation.

The objective of this experiment was to determine the effects of high-peak-power microwaves produced by a virtual cathode oscillator (VIRCATOR) on the performance of rhesus monkeys (<u>Macaca</u> <u>mulatta</u>). In a previous study, we could not demonstrate effects of high-power microwave pulses, produced by a VIRCATOR, on vigilance behavior in rhesus monkeys (1). The monkeys were repeatedly exposed to high-peak-power microwave pulses with the long axis of the animal's body aligned parallel to the microwave magnetic field vector.

Hotspots in the animal body depend on the polarization of the microwave field with respect to the body. In the present study, monkeys were exposed with their body aligned parallel to the electric field vector. Short-duration microwave pulses (50-80 ns) were delivered concurrently with auditory signals to which the monkeys were trained to respond. In sham exposures, an aluminum foil barrier shielded the monkeys from the microwave pulses.

Compared to sham sessions, the microwave pulse did not significantly affect behavioral performance. This study and our previous experiment suggest that exposure to short high-peak-power microwave pulses with very large peak specific absorption rates (SARs) (535.8 to 732.9 kW/kg) but low whole-body average SARs (less than 0.1 W/kg) did not significantly alter a well-trained behavior. Therefore, the whole-body SAR limit of 0.4 W/kg and the part-body SAR limit of 8 W/kg for human exposure to microwave energy remains justified. We recommend additional research on more subjects at other microwave frequencies, pulse repetition rates, and higher power densities.

Acknowledgments

The authors wish to thank the staff for assistance in conducting this experiment at the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico. Special thanks are given to Major Bruce Anderson, Dr. James Metz, Dr. Robert Platt, and Mr. Jeff Christoferson. Without their assistance, the experiments described here could not have been conducted. Dr. Michael Burton and the staff of the Inhalation Toxicology Research Institute, Kirtland Air Force Base, New Mexico, deserve special thanks for excellent care of our monkeys. We also thank Mr. Robert Barrett, Mr. Charles Mogenson, and Rex Dolgner for photographic reproduction, artwork, and video production, respectively. Special appreciation is extended to Mr. Robert Upchurch for assisting in the preparation and conduct of the experiments. Finally, we thank Kathleen Mayer for editorial assistance.

INTRODUCTION

Present safety standards (2,3) recommend limiting microwave exposure of humans to 0.4 W/kg for whole-body specific absorption rate (SAR) and 8 W/kg for localized SAR. The present standards, however, do not limit the instantaneous peak power of pulsed microwave fields. Thus, microwave fields with high-peak powers but low-pulse-repetition rates may satisfy the currently accepted safe maximum permissible exposure limits. The possibility of adverse health effects from pulsed microwave energy with very high-peak power has caused some concern in occupational and military working environments. The most widely studied pulsed microwave-induced bioeffect has been the auditory sensation caused by thermoelastic expansion of brain tissue and a propagating acoustic wave producing stimulation of hair cells in the cochlea (4). The auditory effect requires relatively little peak energy, yet radar and proposed directed energy systems are capable of producing peak powers several orders of magnitude above that required for the effect.

While the auditory effect depends on pulsed microwaves, effects associated with very high-peak-power microwave pulses are unknown. Recent studies have investigated the microwave pulse parameters necessary to produce acoustic mechanical vibrations in brain tissue of several mammalian species (5,6). The concern over adverse health effects stems not from the relatively low-power-microwave pulses necessary to produce auditory stimulation but from very high-peak-power pulses putatively capable of producing intense mechanical vibration in brain tissue. This concern requires further research as new devices with very high-peak-output powers are constantly being developed.

Behavioral experiments have given conflicting results in determining whether pulsed waves (PW) can facilitate behavioral effects more effectively than continuous waves (CW). A recent study (7) found that rats performing on a multicomponent fixed ratio (FR) and timeout (TO) reinforcement schedule were not differentially affected by PW and CW microwaves. In this case, whole-body average SARs of 5.9 and 6.7 W/kg were used for CW and PW exposures, respectively. The peak SAR for the PW exposures was 11.2 kW/kg (authors' estimate). In contrast, others (8) investigated the effect of PW and CW microwaves on rats performing a differential-reinforcement-of-low-rate (DRL) schedule at whole-body average SARs of 0.2-3.6 W/kg and peak SARs of 0.2-3.6 kW/kg (authors' estimate). The rate of appropriately timed responses by rats on this schedule was consistently disrupted by PW microwaves but not by CW microwaves at SARs of 2.5 and 3.6 W/kg. Despite apparent discrepancies, behavioral change continues to be a good indicator for microwave-induced effects. In particular, operant behavior on time-based schedules of reinforcement is very sensitive to microwave exposure (9-11).

A safety standard for exposure to high-peak-power microwave pulses can only be established from an extensive experimental data base. In a previous study (1), we found no significant effects of 2.37-GHz pulsed microwaves on rhesus monkey behavior with a peak whole-body SAR per pulse of 732.9 kW/kg. Because the pulse duration was low (93 ns), the specific absorption (SA) per pulse was only 0.07 J/kg. In that study, the monkeys were repeatedly exposed to high-peak-power microwave pulses with the long axis of the animal's body aligned parallel to the microwave magnetic field vector. Microwave absorption by subjects depends on a variety of factors including wavelength, body size, and orientation of the subject to the microwave fields (12,13). Formation of hotspots of microwave absorption in the animal body will also depend on these same factors (13). In this study, monkeys were exposed with their long axis of the body aligned parallel to the electric field vector to determine if orientation in the microwave fields is an important factor for behavioral effects.

METHODS

SUBJECTS

Four juvenile male rhesus monkeys (Macaca mulatta), obtained from the Naval Aerospace Medical Research Laboratory (NAMRL) primate breeding program, were the subjects. The same monkeys served as subjects in our previous experiment conducted at Kirtland Air Force Base (KAFB), New Mexico (1). The mean weight of the subjects during the present study was 3.75 kg (± 0.09 kg SEM). The subjects were fed a standard primate diet (Wayne Co., 24% protein) daily in sufficient quantities (freely available in their cages) to produce a normal- sized animal for that age. Before training, the animals received a reduced amount of the same diet daily until their body mass decreased by 5% of the previously determined ad libitum weight. During the experiment, the monkeys were maintained near this weight except for periods when they were again free- fed for 5-7 days to establish a new ad libitum weight. This procedure resulted in healthy, well-conditioned animals that worked adequately on food- reinforced tasks. The animals obtained their daily food ration (Noyes Co., 750-mg monkey formula L pellets) while performing the experiment. Their diet during the experiment was supplemented only with fresh fruit. Animals were housed one to a cage where water was always available. Photoperiod was regulated to 12 h light and 12 h dark (0700 on, 1900 off). Home-cage temperature was maintained at 20.2-23.5 °C. During the experiments at KAFB, a mobile trailer was modified to serve as a vivarium and was located just outside the microwave exposure facility. The animals were monitored by the Veterinary care staff at the research facility on KAFB.

APPARATUS

Behavioral

The monkeys were restrained in a Styrofoam chair previously described (14) and were handled by personnel wearing heavy leather gauntlets. The restraint chair was placed inside a large box (108.3 x 81.5 x 86 cm) constructed of Styrofoam panels (5.08 cm thick). The box isolated the monkey from noise produced by the VIRCATOR. In addition, a white-noise source at floor level next to an opening in the rear of the box produced a 75-dBA masking sound inside the box at head level in the restraint chair. Plexiglas sheets (0.32-cm thick) covered windows in the top (25.4 x 30.5 cm) and front (35.6 x 43.2 cm) of the box. We monitored subjects' behavior by the windows, a television camera (Hitachi FP-7), and a video recorder (Panasonic Model No. AG-6400). Velcro tape secured the front and back panels of the box. Room air circulated through the box by a direct-drive blower (Dayton No. 1C982) behind a microwave-absorbent shield. The blower connected to the base of the box by a cloth tube (10-cm diameter, approximately 2-m long). Exhaust air left the box via 10 holes (1-cm diameter) drilled through the top of the back panel of the box.

The chair had two plastic levers (7-cm long, 1.3-cm diameter) mounted vertically and in front of the animal: one to the right and the other to the left. Fiber-optic light switches (Microswitch No. CJWZ-3IIP-B) were activated when the monkey pulled the levers. The fiber-optic switches were connected to light-emitting diodes and light detectors (Microswitch No. FE7C-FR6M) with 15.2-m lengths of fiber-optic cable. The monkey received auditory signals from an audio speaker (10.2-cm diameter). The speaker was mounted in a wooden box covered with fine-mesh copper screen (1.5-mm mesh size) and was placed on the floor of the Styrofoam box. The auditory signals were produced by tone generators and audio amplifiers (BRS/LVE No. AO-201 and No. AA-202). The contingencies for the operant schedule and both data collection and storage were controlled by a microcomputer (Zenith Z-248) and a digital interface (Metrabyte, Dascon-1). Control programs were written in compiled BASIC language (Microsoft Corp. GW-BASIC). The microcomputer system was housed in NAMRL mobile field laboratory No. 1. The mobile laboratory is a temperature-controlled vehicle constructed specifically for field studies. This vehicle was parked next to the microwave exposure building at KAFB.

The Styrofoam box containing the monkey chair was placed on the floor (Eccosorb floor) of the anechoic chamber with the monkey's head positioned 2 m in front of the radial horn and 1.3 m off the center axis of the horn antenna. At this location, the monkey's head was near the center of the annular microwave beam (6 o'clock position) with the long axis of the monkey's body aligned parallel to the electric field vector (E||L). A pellet feeder (Foringer 750-mg) mounted on a Plexiglas stand outside and above the Styrofoam box in the null of the microwave field delivered food pellets to the monkey chair through a 1.2-m length of Tygon tubing.

<u>Microwave Pulse</u>

Microwave exposures conducted at the Beam Physics Branch of the Air Force Weapons Laboratory at KAFB used a VIRCATOR to deliver high-power microwave pulses to a large anechoic chamber (12.2 x 6.1 x 6.1 m). The transformer energized megawatt pulsed output microwave source (TEMPO) is an axially extracted VIRCATOR operated with a center frequency at 2.362 GHz. The VIRCATOR launched microwaves into the anechoic chamber by a custom-designed radial horn antenna (1.21-m diameter). This antenna produced an annular shaped beam, with a null at the center, and radially polarized fields. Microwave energy in the anechoic chamber was measured using an open-ended waveguide (WR-430) terminated with a waveguide-to-coaxial cable adapter. Detected microwave energy was attenuated and applied to a crystal detector (Narda No. 503) and displayed on an oscilloscope (Tektronix No. 7104). Cathode-ray tube displays were photographed for later analysis. The VIRCATOR also produced soft x rays, which were measured at the monkey chair with film-badge photodosimetry.

PROCEDURE

Behavioral Training

Four monkeys from our previous experiment were retrained on a multiple schedule using auditory signals as discriminative stimuli. A schematic of the contingencies of the schedule is shown in Fig. 1. In the first contingency, a 1250-Hz pulsed tone was associated with responses on the right lever during variable interval (VI) schedule (20-s average, 1-84 s range). In the second contingency, 985- and 3395-Hz tones were associated with responses on the left lever (choice reaction time component). A response on the left lever during the 985-Hz signal resulted in a food pellet, whereas a response on the left lever during the 3395-Hz signal resulted in a 10-s timeout and no food pellet. The auditory signals (985 and 3395 Hz) were given in random order for 1-s durations at the end of each variable interval. Behavior sessions were 62 min: three 20-min components with 1-min period between components.

Monkeys received about forty 1-h training sessions (5 days/week) in the Styrofoam isolation box before their air transport to KAFB. After arrival, the monkeys required three to six more training sessions to reestablish stable performance. Microwave and sham exposures were given during the middle 20-min component of each session with microwave pulses presented during the tone-discrimination period (either 985 or 3395 Hz). All training sessions at KAFB, as well as sham- and microwave-exposure sessions, were videotaped for later analysis. In each experiment, we used five primary dependent variables to evaluate behavioral performance: total right-lever responses, left-lever reaction time, postreinforcement pause (elapsed time between delivery of a food pellet and the first right-lever response on the next VI), postchoice pause; (elapsed time between a 3375-Hz tone and the first right-lever response on the next VI), and total errors on the left lever.

Microwave Exposure

Two microwave and two sham exposures were conducted. Three of the monkeys received a microwave and sham exposure wherein audible noise from the VIRCATOR proved to be an artifact. Subsequently, their microwave and sham exposures were repeated for all subjects after the audible VIRCATOR noise was reduced by placing sound-absorbing insulation around the radial horn antenna outside of the anechoic chamber and adding additional Styrofoam panels to the Styrofoam box containing the monkey. Additional details of the exposures are given in Table 1.

The microcomputer triggered microwave pulses just before presentation of an auditory signal (either 985 or 3395 Hz) to the monkey. Sham exposures were conducted in a similar manner, except microwaves were blocked from the monkey by a Styrofoam sheet (1.2-m diameter, 5.1-cm thick) covered with aluminum foil and inserted into the radial horn antenna. For microwave exposures, the foil was removed from the Styrofoam sheet. In a repeated-measures experimental design (15), the monkeys were given microwave or sham exposures on different days, in a random order, while they performed the behavioral task.

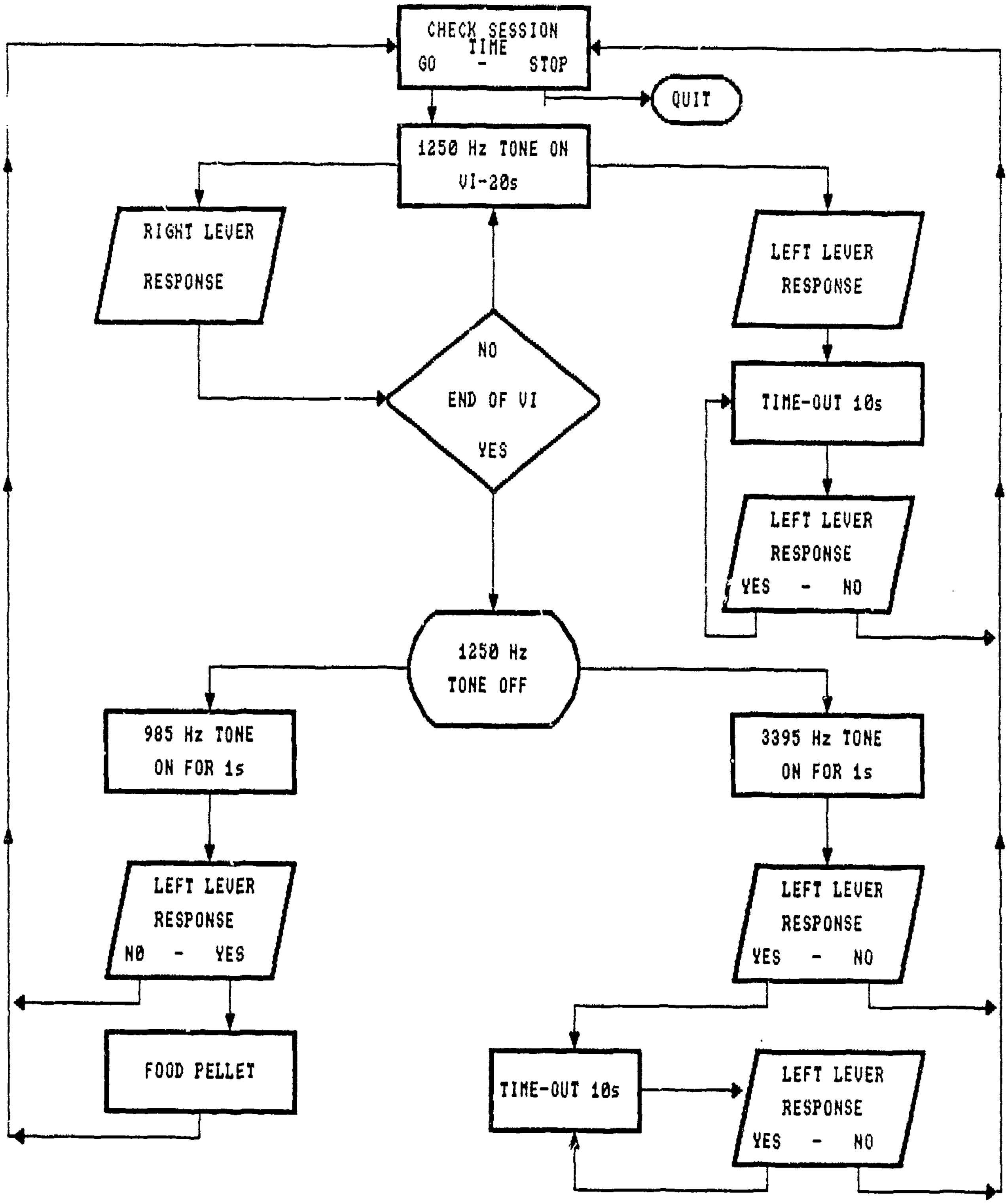


Figure 1. Schematic diagram of the behavioral task performed by monkeys during microwave and sham exposures.

TABLE 1. Microwave and Sham Exposure Session Summary.

Monkey	Microwave I		Sham I		Microwave II		Sham II	
	Shots[a]	PD[b]	Shots	PD	Shots	PD	Shots	PD
#64	53	6.57	48	< .03	57	7.72	58	< .03
#24	41	6.78	38	< .03	54	8.07	52	< .03
#57	46	6.75	49	< .03	50	8.09	50	< .03
#32	--	----	--	------	46	7.64	45	< .03

[a]Number of microwave pulses.
[b]Mean peak power density in kW/cm².
Center frequency was 2.36 GHz.
Power density range was 5.36-12.16 kW/cm².
Pulse duration range was 50-80 ns.
Field polarization was E||L.

DOSIMETRY

We could not measure local and whole-body SAR because of the extremely short-duration VIRCATOR-produced microwave pulses. Consequently, we estimated the SAR at 2.3 GHz using both an analytical model (16) and empirical estimates of monkey models exposed to 2.3-GHz CW microwaves in an anechoic chamber at NAMRL.

Analytical Dosimetry

The predicted whole-body SAR for a sitting rhesus monkey exposed to 2.3-GHz microwaves is 0.068 W/kg per mW/cm² (16). We used this value with the field power densities measured at the monkey location in the exposure chamber (exposure II) to calculate a whole-body SAR per pulse of 535.8 kW/kg (range = 365-827 kW/kg per pulse).

Empirical

To obtain empirical SAR estimates, we exposed monkey surrogates in an anechoic chamber to CW radiation at 2.37 GHz with the long axis of the surrogate parallel to the electric field vector. An estimate of the local SAR at four body locations was determined using a bag monkey model (5.05 kg), similar to that used by Olsen and Griner (17), filled with simulated muscle tissue (18). A monkey model was mounted in the Styrofoam chair and placed in an anechoic chamber facing a standard-gain horn antenna (Narda No. 612). Four small plastic cannulae were inserted in the model from the rear: two cannulae in the head (7-cm diameter) on the center axis (1 and 3 cm in from the front surface); one cannula 3 cm from the front surface of the neck, and one cannula 8 cm from the front surface in the chest region. Microwave-compatible temperature probes (Luxtron No. 750) were inserted into each cannula.

Temperature of the model was recorded at 30-s intervals before, during, and after microwave exposure. If the temperature remained stable for several minutes, a 6-min microwave exposure was given using a 1-kW microwave source (MCL, Inc.) producing an average power density at the location of the model of 63.0 mW/cm^2, as measured by a field probe (Narda No. 8323). The model was exposed three times allowing the temperature to stabilize between each exposure. The local SAR was calculated using the following formula: SAR (W/kg) = cT/t, where T is the temperature change in degrees Celsius, c is the specific heat in J/kg/°C, and t is the exposure time in seconds. The mean local SAR based on three exposures resulted in the following SARs (normalized to 1 mW/cm^2): head 1-cm 0.52 W/kg, head 3-cm 0.06 W/kg, neck 0.06 W/kg, and chest 0.15 W/kg.

We estimated the whole-body SAR empirically using plastic bottles (3-liter volume, 33-cm length, 13-cm diameter) filled with physiological saline. The bottles were placed in the Styrofoam chair and exposed to microwave radiation for 10 min. The SAR was calculated using the formula given above. The mean normalized SAR based on 4 exposures of the saline-filled plastic bottle was 0.059 W/kg (± 0.005 W/kg SD). This value is very close to the 0.068 W/kg predicted by the Radiofrequency Radiation dosimetry Handbook (16).

) ing Radiation

The VIRCATOR produces large amounts of soft x rays from which the monkey must be protected by lead shielding. To monitor the effectiveness of the shielding, each monkey was assigned a film badge for cumulative exposure across all sessions, as well as another film badge to measure skin-dose x-ray exposure during a single session. The cumulative exposure dosimetry range was 122-290 mR; the range for single-session exposures was 41-53 mR. The skin dose of x rays received by the monkeys was well below the recommended safe human occupational exposure level (19).

RESULTS

MICROWAVE AND SHAM EXPOSURES I

During the first set of microwave and sham exposures, behavioral orienting responses to the VIRCATOR shots were quite evident. The monkeys, which were observed on the closed-circuit television monitor during microwave or sham exposure, would stop responding and look from side to side. Orienting responses continued throughout the exposures. Changes in responding on the right lever (VI lever) during the exposures given in the middle 20-min component (exposure) are shown in Fig. 2. Repeated-measures analysis of variance and multiple comparisons were used to test for significant effects (15). Total responses during both sham and microwave-exposure sessions were dropped significantly ($F(2, 4) = 13.19$, $p < 0.05$) from either the pretest or posttest components. The difference between sham- and microwave exposure-sessions was not significantly different ($p > 0.05$) indicating that possibly an auditory artifact existed during the exposures and not an effect of the microwave pulses.

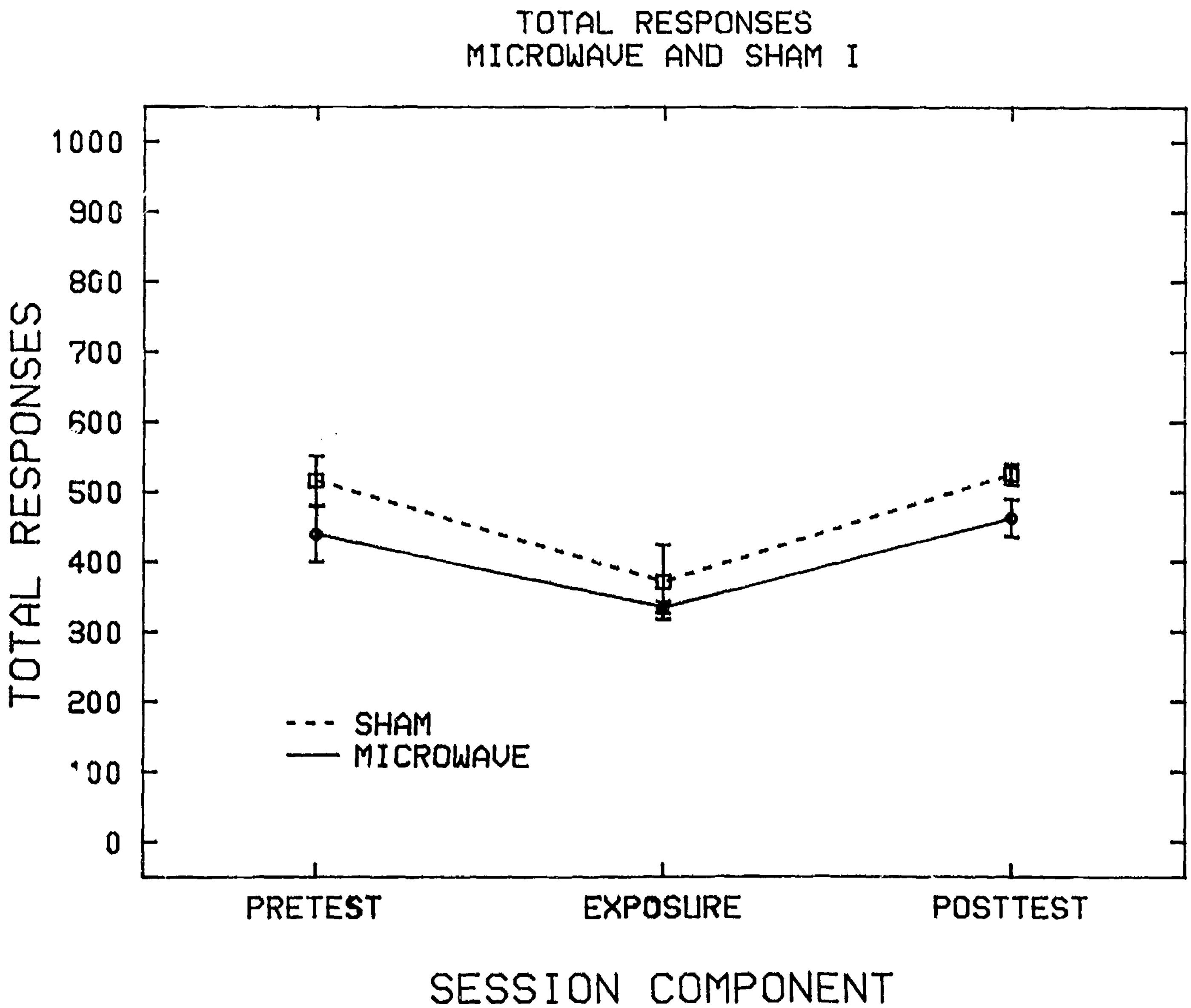


Figure 2. Mean total responses (± SEM) emitted during each session component during microwave exposure I and sham exposure I.

MICROWAVE AND SHAM EXPOSURES II

After additional sound insulation was added to the outside of the anechoic chamber and Styrofoam monkey enclosure, the experiments were repeated without further behavioral orienting to the sound. During the initial few microwave pulses of the second series, some orienting was noted in two monkeys, but this response habituated rapidly with no lasting effect on overall performance of the vigilance task.

Compared to sham-exposure sessions (sham II), microwave pulses (microwave II) did not produce statistically significant effects on behavioral performance. Total responses emitted during each 20-min session component are shown in Fig. 3. Compared to components 1 (pretest) and 3 (posttest), microwave exposures, given during component 2 (exposure), did not alter the number of responses emitted by each monkey as compared to the sham exposures ($p > 0.05$). Similarly, reaction time on the left lever (Fig. 4) did not show a significant difference between microwave and sham exposure ($p > 0.05$). Likewise, postreinforcement pause (Fig. 5) was not altered by the high-peak-power microwave pulses as compared to the sham exposures ($p > 0.05$). Finally, neither postchoice pause (Fig. 6) nor the errors on the left lever differed significantly between the microwave exposures from the sham exposure and ($p > 0.05$).

DISCUSSION

These results show that exposure to short high-peak-power microwave pulses with very large peak SARs but low whole-body average SARs did not significantly alter a well-trained behavior. This outcome supports our previous experiment (1) conducted at the KAFB exposure facility. The SARs during both experiments were well below the average whole body SAR threshold (4 W/kg) known to disrupt behavioral performance (2). The use of high-peak-power pulses in these experiments did not suggest that the threshold was lower than 4 W/kg. Also, the specific absorption (SA of 200-300 J/kg) for each session was well below the safety standard (2) for the local SA of 2880 J/kg (8 W/kg x 6 min). While two of the monkeys exhibited some observable orienting to the first few microwave pulses of the exposure session, we could not determine whether audible noise produced by the pulse was responsible for this minor effect. Nevertheless, no lasting effects could be observed on overall performance of the task. The microwave pulse parameters used in this study, however, are only a small sample of the many possible parameters that need to be examined before meaningful extrapolation of the animal results to human performance effects and hazards can be done.

This experiment did not provide evidence of high-peak-power microwave pulse hazards. Therefore, the SAR limits of 0.4 W/kg (whole body) and 8 W/kg (localized) for human exposure to microwave energy remain justified. We recommend additional research on more subjects at other microwave frequencies and higher peak-power densities.

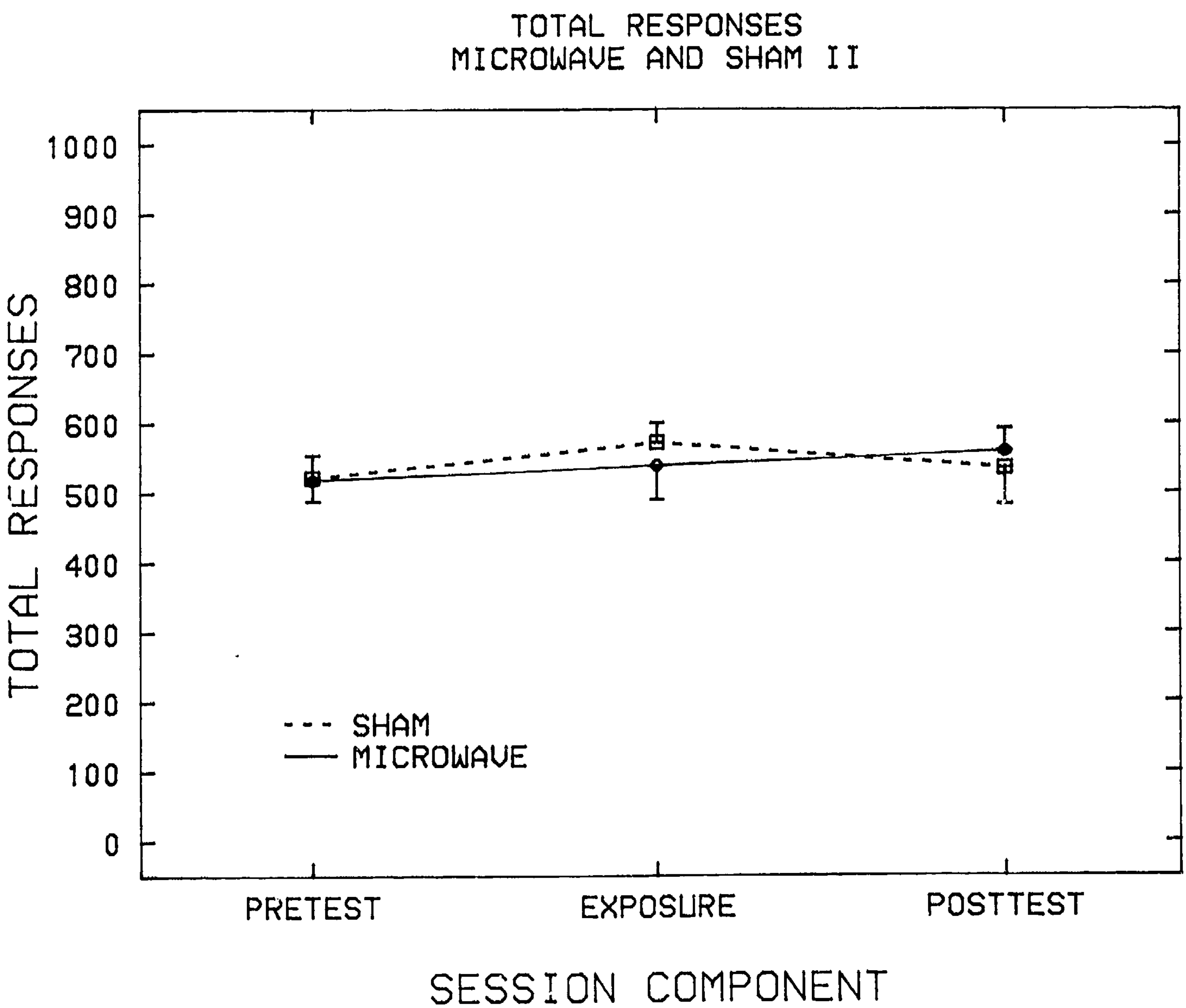


Figure 3. Mean total responses (± SEM) emitted during each session component during exposures to microwave (II) and sham (II) exposures.

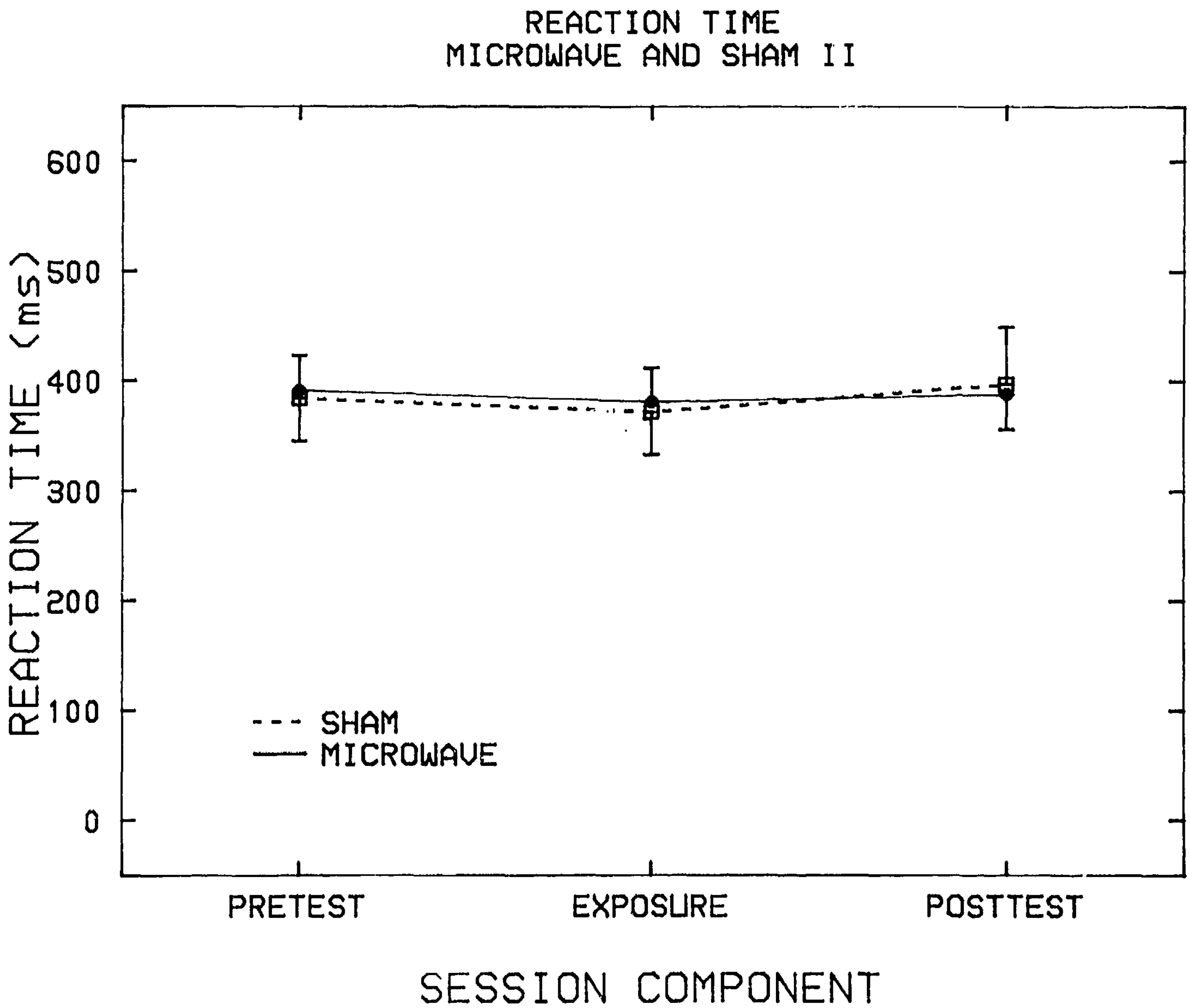


Figure 4. Mean reaction time (± SEM) following presentation of the 985-Hz tones during each session component.

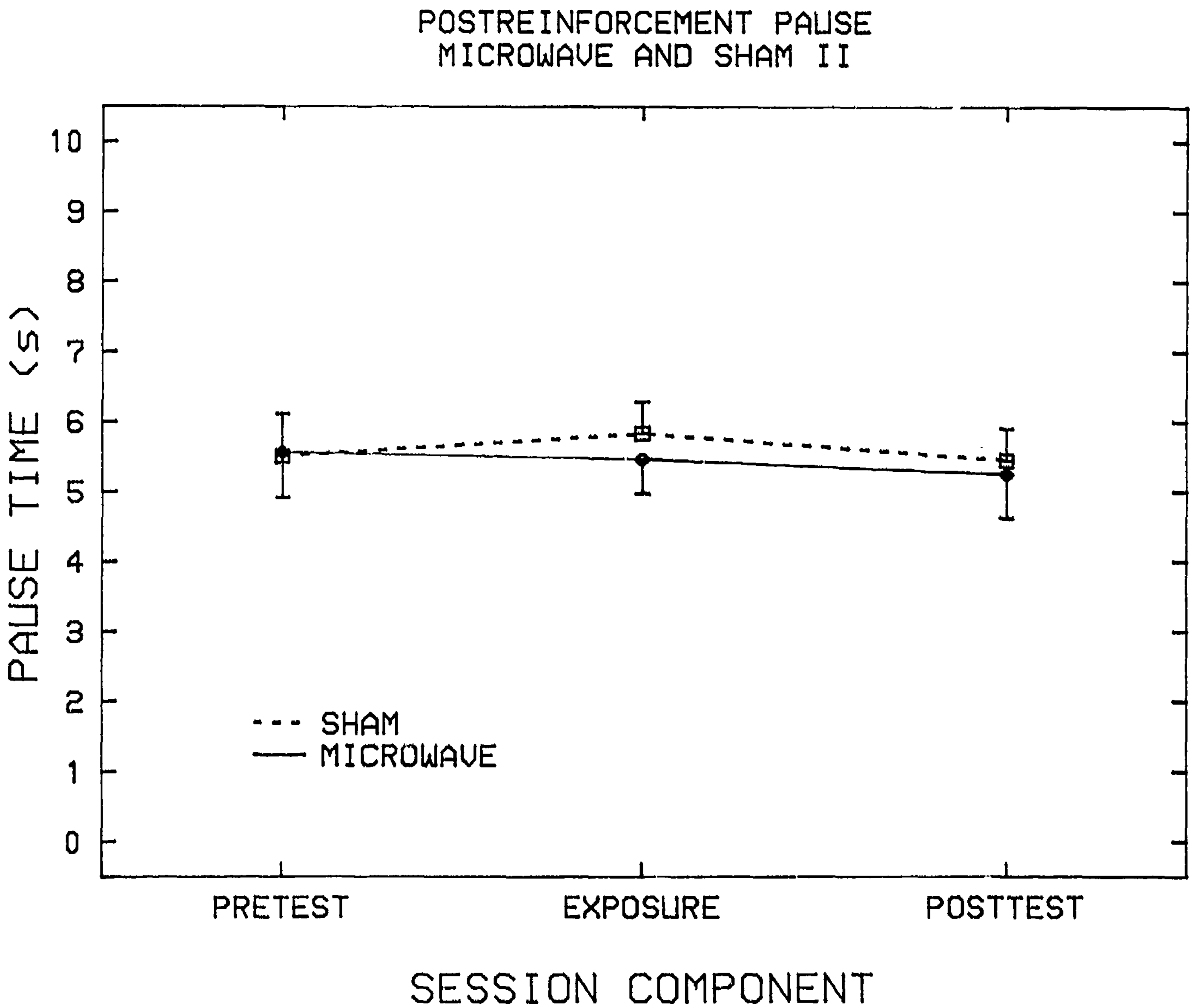


Figure 5. Mean postreinforcement pause time ± SEM measured during each session component during exposures to microwave pulses and sham exposures.

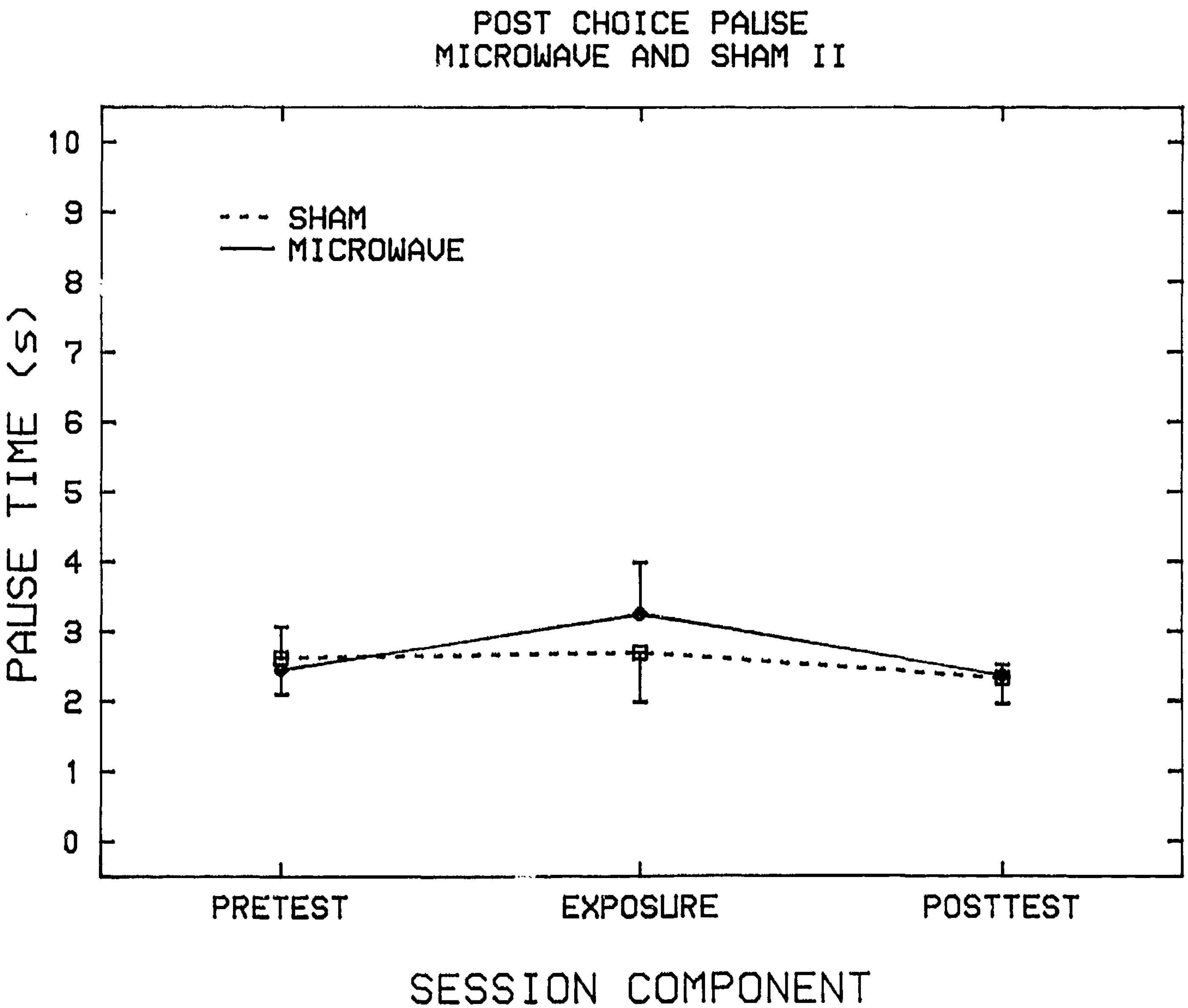


Figure 6. Mean postchoice pause time ± SEM measured during each session component during exposures to microwave pulses and sham exposures.

REFERENCES

1. D'Andrea, J.A., Knepton, J., and Cobb, B.L., High Peak Power Microwave Pulses at 2.37 GHz: No Effect on Vigilance Performance in Monkeys, NAMRL-1348/USAFSAM-TR-89-21, Naval Aerospace Medical Research Laboratory, Pensacola, FL, November 1989. (AD A219 570)

2. American National Standard Safety Levels with Respect to Human Exposure to Radio Frequency Eletromagnetic Fields, 300 kHz to 100 GHz, ANSI C95.1-1982, The Institute of Electrical and Electronic Engineers, Inc., New York, NY, 1982.

3. Biological Effects Exposure Criteria for Radiofrequency Electromagnetic Fields, NCRP Report No. 86, National Council on Radiation Protection and Measurements, Bethesda, MD, 1986.

4. Lin, J.C., Microwave Auditory Effects and Applications, Charles C. Thomas, Springfield, IL, 1978.

5. Olsen, R.G. and Hammer, W.C., "Microwave-induced Pressure Waves in a Model of Muscle Tissue." Bioelectromagnetics, Vol. 1, pp. 45-54, 1980.

6. Olsen, R.G. and Lin, J.C., "Microwave-induced Pressure Waves in Mammalian Brains." IEEE Transactions on Biomedical Engineering, Vol. BME-30, No. 5, pp. 289-294, 1983.

7. Lebovitz, R.M., "Pulse Modulated and Continuous Wave Microwave Radia tion Yield Equivalent Changes in Operant Behavior of Rodents." Physiology and Behavior, Vol. 30, No. 6, pp. 891-898, 1983.

8. Thomas, J.R., Schrot, J., and Banvard, R.A., "Comparative Effects of Pulsed and Continuous Wave 2.8 GHz Microwaves on Temporally Defined Behavior." Bioelectromagnetics, Vol. 3, pp. 227-235, 1982.

9. Sanza, J.N. and de Lorge, J.O., "Fixed Interval Behavior of Rats Exposed to Microwaves at Low Power Densities." Radio Science, Vol. 12, No. 6S, pp. 273-277, 1977.

10. D'Andrea, J.A., Gandhi, O.P., and Lords, J.L., "Behavioral and Thermal Effects of Microwave Radiation at Resonant and Nonresonant Wavelengths." Radio Science, Vol. 12, No. 6S, pp. 251-256, 1977.

11. de Lorge, J.O., "Operant Behavior and Colonic Temperature of *Macaca mulatta* Exposed to Radio Frequency Fields At and Above Resonant Frequencies." Bioelectromagnetics, Vol. 5, pp. 233-246, 1984.

12. Gandhi, O.P., "Frequency and Orientation Effects on Whole Animal Absorption of Electromagnetic Waves." IEEE Transactions on Biomedical Engineering, Vol. 22, pp. 536-542, 1975.

13. Gandhi, O.P., Hunt, E.L., and D'Andrea, J.A., "Deposition of Electromagnetic Energy in Animals and in Models of Man With and Without Grounding and Reflector Effects." Radio Science, Vol. 12(6S), pp. 39-48, 1977.

14. Reno, V.R. and de Lorge, J.O., "A Primate-restraint device for use in Microwave Biological Research." IEEE Transactions on Biomedical Engineering, Vol. 24, pp. 201-203, 1977.

15. Kepple, G., Design and Analysis: A Researcher's Handbook, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1973.

16. Durney, C.H., Johnson, C.C., Barber, P.W., Massoudi, H., Iskander, M.F., Lords, J.L., Ryser, D.K., Allen, S.J., and Mitchell, J.C., Radiofrequency Radiation Dosimetry Handbook, USAFSAM-TR-78-22, Brooks Air Force Base, San Antonio, TX, 1978.

17. Olsen, R.G. and Griner, T.A., "Outdoor Measurement of SAR in a Full-Sized Human Model Exposed to 29.9 MHz in the Near Field." Bioelectromagnetics, Vol. 10, No. 2, pp. 161-171, 1989. (AD A208 392)

18. Chou, C.K., Chen, G.W., Guy, A.W., and Luk, L.H., "Formulas for Preparing Phantom Muscle Tissue at Various Radiofrequencies." Bioelectromagnetics, Vol. 5, pp. 435-441, 1984.

19. Recommendations of Limits for Exposure to Ionizing Radiation, Report No. 91, National Council on Radiation Protection and Measurements, Bethesda, MD, 1987.

Other Related NAMRL Publications

D'Andrea, J.A. and Cobb, B.L., High Peak Power Microwave Pulses at 1.3 GHz Effects on Fixed Interval and Reaction Time Performance in Rats, NAMRL-1337, Naval Aerospace Medical Research Laboratory, Pensacola, FL, December 1987. (AD A199 489) *

de Lorge, J.O., The Thermal Basis for Disruption of Operant Behavior by Microwaves in Three Animal Species, NAMRL-1286, Naval Aerospace Medical Research Laboratory, Pensacola, FL, June 1982. (AD A127 370) *

de Lorge, J.O., "Effects of Microwaves on Scheduled-controlled Behavior." In J.C. Monahan and J.A. D'Andrea (Eds.), Behavioral Effects of Microwave Radiation Absorption, HHS Publication FDA 85-8238, August 1985, pp. 22-35.

Olsen, R.G., Griner, T.A., and Prettyman, G.D., "Far-field Microwave Dosimetry in a Rhesus Monkey Model." Bioelectromagnetics, Vol. 1, pp. 149-160, 1980.

Olsen, R.G. and Lin, J.C., "Microwave Pulse-induced Acoustic Resonances in Spherical Head Models." IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-29, pp. 1114-1117, 1981.

Other Related USAFSAM Publications

Cordts, R.E., Merritt, J.H., Erwin, D.N., Hardy, D.N., and Yochmowitz, M.G., Behavioral Response of Rats Exposed to High-Power Microwave Radiation, USAFSAM-TR-87-30, USAF School of Aerospace Medicine, Brooks Air Force Base, TX, February 1988. (AD A192 199) *

Klauenberg, B.J., Merritt, J.H., and Erwin, D.N., Behavioral Effects of Exposure to the TEMPO High Power Microwave System, USAFSAM-TR-87-35, USAF School of Aerospace Medicine, Brooks Air Force Base, TX, March 1988. (AD A193 305) *

* Available from DTIC, Cameron Station, Alexandria, VA 22314 (Phone: (Commercial) 202/274-7633 or (AV) 284-7633).